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ΦSCUBA

A BUFFERED CORE GRAPHICS SYSTEM

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ABSTRACT

The graphics community is recently taking a close look at graphics standardization prompted by issues such as portability of software, application program structure, diverse hardware, etc. Through these efforts, the Graphic Standards Planning Committee of ACM/SIGGRAPH has proposed a standard. This standard advocates four levels of the Core system, namely basic, buffered, interactive and complete. This paper describes a Level 2 (i.e. buffered) implementation of the Core system in APL, referred to as ⌽*SCUBA* (*A*PL *BU*ffered *C*ore *S*ystem). The details of the structure and organization of ⌽*SCUBA* are given. The implementation is highly modular in nature, provides both two and three dimensional capabilities with several types of projective transformations and supports full segmentation capabilities. Several examples illustrating the use of the system are included. The interactive nature of APL is found to be attractive. Some deviations from the Core system have been incorporated. These include a modular hardcopy interface to produce graphics on plotters etc. and a facility to retain world coordinates of the objects. The system, though appearing to be satisfactory, has to undergo further testing to gain user confidence.

1. INTRODUCTION:

ΦSCUBA (APL BUffered Core System) is an APL based system for generating and maintaining graphics displays. The system is implemented under APLSV to run on an IBM 370/3032 at the University of New Brunswick. It has been designed and developed to meet the functional capabilities of the Level 2 Core System proposed by the Graphics Standards Planning Committee of ACM/SIGGRAPH in July of 1977 [GSPC77].

The main objectives in developing ΦSCUBA are device independence, adherence to CORE specifications and maintenance of pictures as simple user files. Device independence implies that it should be possible to draw on any graphics devices currently supported, which include storage tubes, a drum plotter, an electrostatic plotter and line printers. Close adherence to CORE specifications is the second design goal; Level 2 is chosen because of hardware limitations. Thirdly, maintenance of pictures as user files is prompted by the fact that the application programmer is essentially an APL user and hence has to manage the available workspace area. In terms of capabilities, the system is capable of producing 2D or 3D pictures or 2D plots using graphics primitives like MOVE and DRAW for the creation of pictures. Also, full general viewing specifications are available to create several images (projections) of the same object. Finally, facilities to interact with the objects and/or images in terms of changes or transfers to other devices are provided.

In the following sections a brief discussion of the structure, implementation and the highlights of ΦSCUBA is presented.

II. STRUCTURE OF ΦSCUBA:

The complete system has been organized in terms of groups of APL functions. Three essential groups (CORE1, CORE2, CORE3) form the bulk of Level 2 Core System specifications and CORE4 forms the modelling system for *ΦSCUBA*. Additional groups comprise the global variables, device drivers and device dependent routines, and the backbone of the TSIO filing facility. Finally, a hardcopy interface forms a separate group which helps in transferring pictures to plotters and printers not directly supported under the APLSV system.

Figure 1 depicts the general organization of *ΦSCUBA* and the overall flow of information in the system. The groups have been combined to form modules for the sake of clarity.

In conforming to the CORE specification [GSPC77], the modelling system is separated from the viewing system. This dichotomy not only helps in achieving a clean system but also saves valuable workspace area in APL since the user can dynamically release storage used by the modelling system functions.

Module 'C' comprising of CORE1, CORE2 and CORE3 forms the complete device independent Level 2 Core System. The functions in CORE1 implement all the output primitives, viewing transformations, and the general 3D clipping. CORE2 forms the segment operations submodule and has functions to generate and maintain picture segments and associated data structures. A slight deviation from CORE specifications is to be found here in terms of object data structures and retaining of objects in

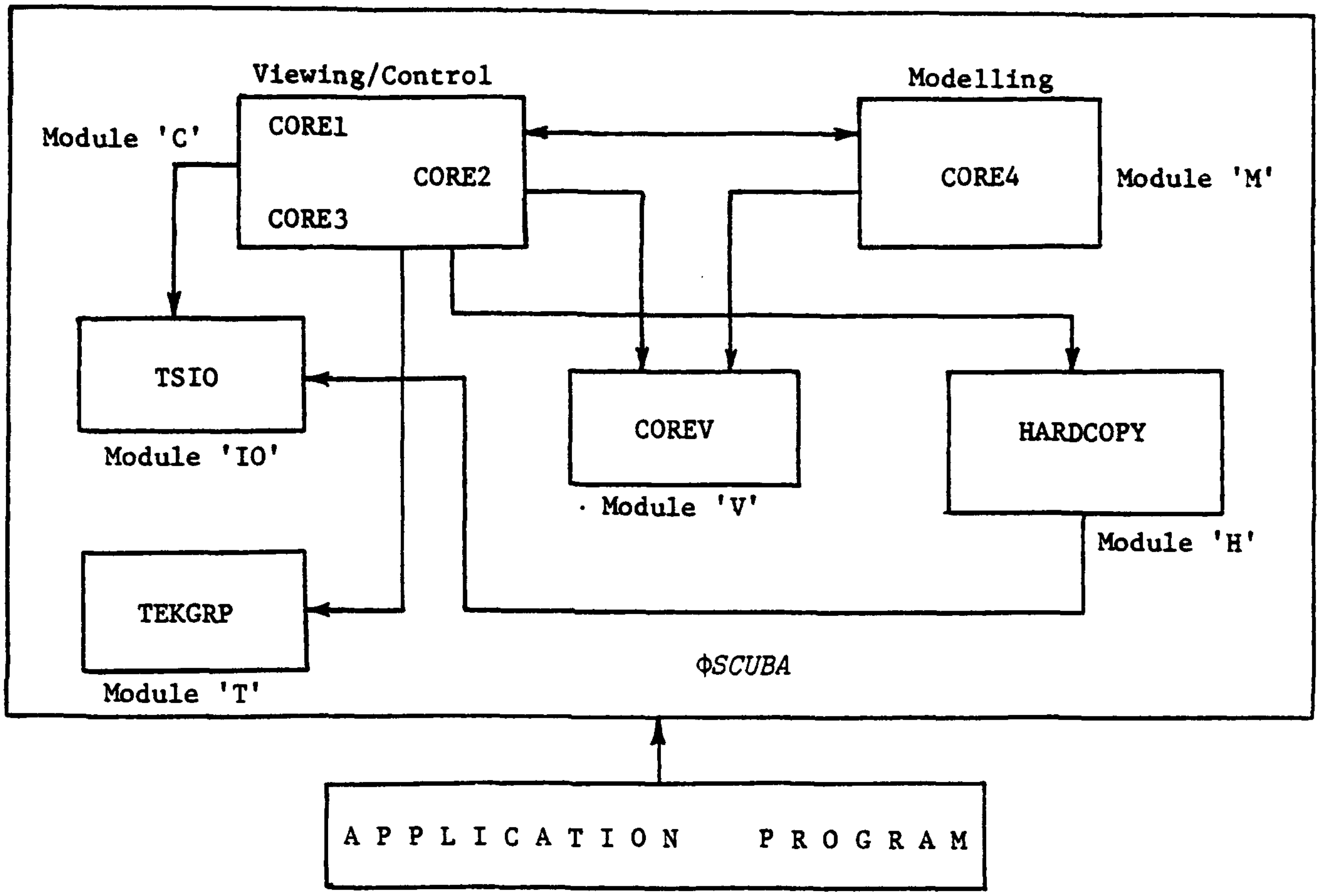

Figure 1: Organization of *ΦSCUBA*

addition to the images. The details are discussed later under implementation. Finally, CORE3 implements the control functions of the CORE specifications such as setting and inquiry of attributes, selecting viewing control parameters, etc. Instead of leaving the application programmer to make individual function calls (as specified by GSPC) for various settings or inquiries, one interactive function for each set of attributes (say, viewing or control or primitive) is written for this purpose. This approach is found to be of valuable use in the implementation of some of the CORE functions.

Module 'M' is the modelling functions module used to describe the orientation or position of the object in the world coordinate system. This module is used in conjunction with the module 'C' since the initial object definition is to be through primitive invocations in an open segment.

Module 'V' is entirely made up of global variables used by the system. It contains such items as representative data structures for objects and images, list of viewing parameters, some 'HELP' documentation, etc.

Module 'IO' consists of essential TSIO routines for creation and maintenance of retained segments. Any errors that are detected in this module are passed on to the higher level routines in module 'C' for reporting.

The module 'T' consists of device drivers (currently only TEKTRONIX 4015 storage display drivers) and thus form the device dependent portion of the ΦSCUBA system. The functions of this module can be used for line drawing, character writing, screen erasing, etc. It also includes some global variables like character stroke table, screen dimensions and control characters.

The hardcopy interface in module 'H' consists of a specialized set of routines which transfer pictures drawn on the TEKTRONIX display to any of the other plotting devices not supported under APLSV. The technique used is to record all the 'pen movements' in a TSIO file as the picture is constructed and use this file as an input to the 2D

plotting package [GUJA72, GUJA76] available under the general operating system. The details of this module are explained under implementation.

The overall structure of *ΦSCUBA* lends itself to easy application programming. A majority of the functions are niladic and any input expected of the user is handled interactively via a conversation. Thus the application programmer's knowledge of APL has essentially been kept to the minimum. Error reporting, although done through individual functions, is organized so as to avoid occurrences of suspended functions and holding of storage space. A knowledgeable APL programmer, however, can make use of the facilities of *ΦSCUBA* much more efficiently by defining his/her own functions using the *ΦSCUBA* functions. By doing so, the user can obtain the intended results in a faster way.

III. IMPLEMENTATION DETAILS:

The implementation langauge being APL, its dynamic array handling capabilities are extensively used. All the data are represented as real arrays thus maintaining a consistent storage structure. For retaining purposes the available TSIO facilities [UNB74] under APLSV are used. The character strings appearing in text are converted to equivalent real constant by using the encoding operator of APL. This proves to be simple and economical on storage. Figure 2 summarizes the structure of the various arrays used for storing objects and their images; the following notation is used in that Figure:

XW,YW and ZW are the world coordinate dimensions of a point,

XI,YI are the transformed dimensions representing the image of a point,

0 OR 1	XW	YW	ZW
0 OR 1	XW	YW	ZW

N × 4

0 for MOVE
1 for DRAW

a) Wire frame drawing in world coordinates.

SYMBOL#	XW	YW	ZW
SYMBOL#	XW	YW	ZW

N × 4

SYMBOL# = Index in the APL symbol set

b) Markers in world coordinates.

XW	YW	ZW	HTW	WDW	XSP	YSP
XI	YI	R	XSPI	YSPI	HTI	WDI
LENGTH	TEXT CODE	TEXT CODE	TEXT CODE	TEXT CODE	TEXT CODE	

c) Text Vector - World definition and/or corresponding image.

EP1		EP2	
XI	YI	XI	YI
XI	YI	XI	YI

N × 4

EP1 - End Point 1
EP2 - End Point 2

d) Image of wire frame drawing.

SYMBOL#	XI	YI
SYMBCL#	XI	YI

N × 3

SYMBOL# = Index in the APL symbol set

e) Image of markers.

Figure 2: Data structures for objects and images

XSP,YSP,XSPI,YSPI are the spacing parameters in a line of text in the world and image coordinates respectively,

HTW,WDW,HTI,WDI are the character size parameters in world and image coordinates respectively and

R is the angle, in radians, of inclination of the text string; it is calculated internally.

At Level 2, the Core System provides everything except detectability of segments, input primitives and image transformations. Thus, all the output primitives and their attributes (excepting some device dependent ones like text font, color and highlighting) are implemented. In implementing the text primitives, only the low quality text is chosen. The high quality text is too expensive to implement and the medium quality text, it is felt, does not offer any great advantage over the low quality. In fact, the medium quality text has the disadvantage of overlapped characters (see examples in [GSPC77]). A software stroke chracter generator to produce standard APL character set of 120 symbols is provided.

To implement the viewing transformations, the synthetic camera analogy of the Core System [NEWM78, GSPC77] is used. The user could choose a particular view from the six possible views: perspective, oblique, isometric, top, front and side. The latter four are particular cases of orthographic projections; certain viewing parameters are set automatically by the system for these views. The user must be knowledgeable of the viewing transformations to set the particular parameters for getting two or three point perspectives or a particular cabinet or cavalier projection. The mathematics used in this implementation

is based on the paper by Carlbom and Paciorek [CARL78] and discussions by Rogers and Adams [ROGE76] and Newman and Sproull [NEWM73].

A general 3D clipping is employed for world coordinate clipping where the particular viewing volume (infinite or truncated pyramid or parallelopiped) is derived from the viewing parameters. An algorithm given by R.F. Puk [PUK77] is implemented for achieving the above clipping. The clipping (both window and depth) is user controllable and the options have been included as control parameters along with the type of world coordinate system (left or right).

Picture segmentation and naming facility of the Core System is implemented through the segment operations submodule and the TSIO module. A segment is created by invoking the CREATE function. The created segment can be either named or unnamed and can be retained or nonretained. Only nonretained segments can be nameless. Any created segment results in the creation of an entry in a system maintained segment directory (see Figure 3). An entry in the segment directory shows an eight character segment name (padded with blanks to the right, if needed) and three flags associated with visibility, type and residence. The visibility and the type are directly the segment attributes of the Core System. The residence flag is a special flag which indicates the presence or absence of the world coordinate definition of a particular segment in the APL workspace. This additional feature is prompted by the facility to retain objects in addition to the images in a segment. More details of this new facility are discussed in the following section.

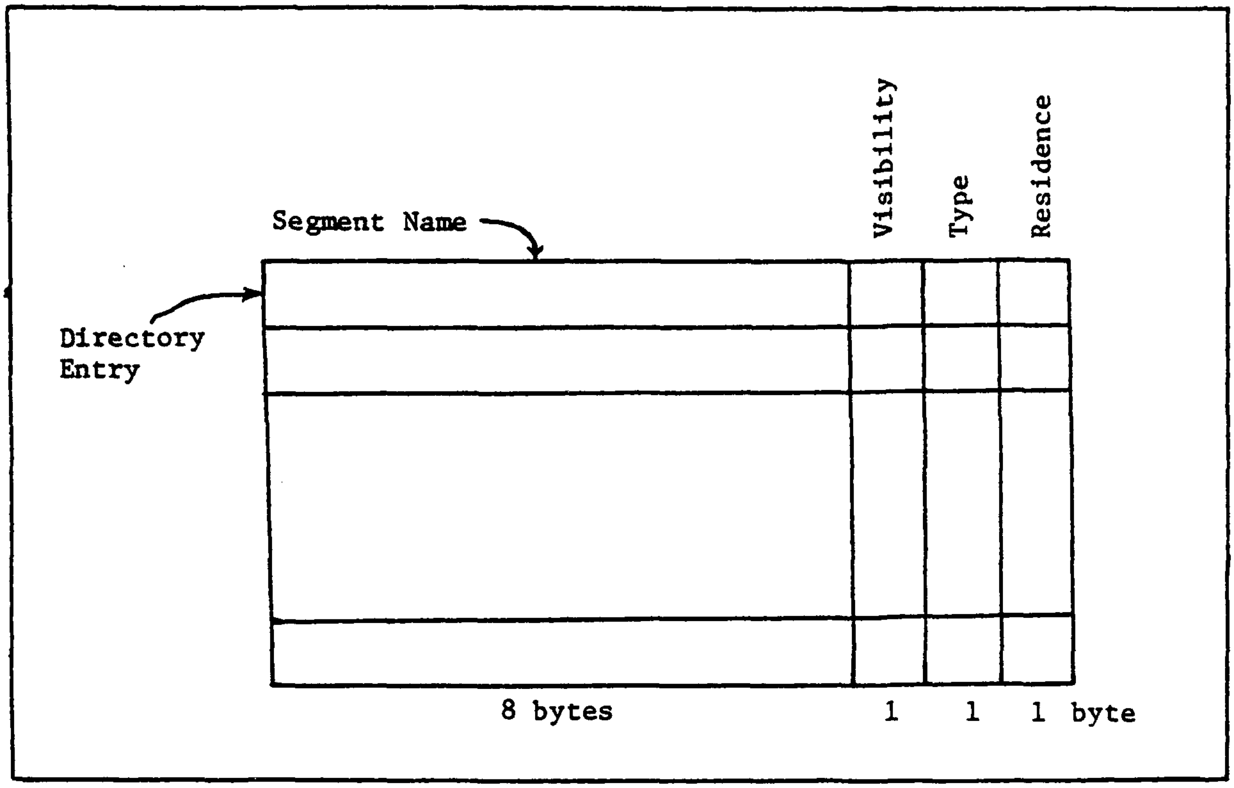

Figure 3: Segment Directory

For each created segment, there can possibly be two TSIO files - one for image and one for object. In addition, each user will have his/her segment directory as a TSIO file which is augmented each time a segment operation affecting the segment directory is performed. At any time the user can inquire the contents of his/her segment directory by means of a LISTDIRY function. Independent loading and storing of the directory is also possible by means of LOADDIRY and STORDIRY functions.

The double buffering required in Level 2 of the Core System [GSPC77] has been achieved through RENAME function. In addition, a NAME function has been provided which can be used to name an unnamed segment. This feature helps the user to work on an unnamed segment initially until the segment appears to be satisfactory; at this time a name can be

attached to retain the segment, if desired.

As mentioned before, the CORE functions are implemented in an interactive mode via a conversation with the user. Typically, setting up of the viewing parameters, segment attributes and primitive attributes is handled via niladic functions such as SETVIEW or SETPRAT. Similarly, inquiry of attribute values is handled via the INQUIRE function. Clearly, this scheme can be employed either separately or inside other functions developed by an application programmer.

Error handling has been achieved through individual functions themselves rather than through a separate error handler. However, depending on the severity of an error, the user is either prompted to continue with a corrective action (e.g. duplicate segment name error) or to terminate current activity through a return to the highest level of function call. The latter is achieved in APL very easily through execution of a niladic branch arrow. Care has been taken to see that the user is not confronted with incomprehensible error situations. Even in the worst case of a workspace overflow, an elementary knowledge of APL and of the names of the modules of the system will help the user to dynamically expunge some variables to make room in the workspace in order to continue execution.

The implementation of an auxillary hardcopy interface for the ⌽*SCUBA* system is necessitated by the nonavailability of other devices such as plotters under APLSV. Currently, a device independent plotting system [GUJA72, GUJA76] is available for FORTRAN users in the Computing Centre

of the University of New Brunswick. The package takes in two dimensional plotting data to plot lines, curves and text strings. Special needs such as line styling are handled by special routines. The interface consists of a FORTRAN program which is submitted through the RJE/RJO facility of APLSV [GUJA75] on behalf of the user of the Φ*SCUBA* system. The input to this FORTRAN program is a plot file constructed out of the device coordinates determined at the time of image construction. This plot file is prepared dynamically as the image is displayed on the view surface of the Φ*SCUBA* system. A simple sequential file structure is chosen for this plot file which is constructed as a TSIO file. The details of this file structure are reported elsewhere [NAGE79].

The user intending to get a hardcopy has to first initialize his/her plotfile before invoking the Φ*SCUBA* functions. After displaying the required image, transfer to other devices is handled via an interactive routine TRANSFER which allows the user to specify the device, size of plot, etc. and prepares a remote job to be submitted to the system 370 through RJE/RJO facility [GUJA75]. The output from this job will be the user's hardcopy.

A complete summary of the Φ*SCUBA* functions is given in Appendix II.

IV. DEVIATIONS FROM CORE SYSTEM:

One important deviation from the CORE specifications is the facility to retain the object in the world coordinate system. There are two reasons for this. Firstly, this feature conserves the workspace. Secondly, although the image retaining facility allows one to keep

several images of the same object, the advantage of retaining one object definition and viewing it under different viewing conditions interactively seems to be more desirable. Thus three functions, LOAD, STORE and ERASE, are written to work with objects; a residence flag in the segment directory entry indicates the presence or absence of the object in the active workspace. One other advantage of this facility is that viewing of two or more different objects under the same viewing setup is possible.

The file structure for objects is similar to that for images. Line definitions and/or text definitions and/or marker definitions are all stored as sequential real numbers in fixed blocked records. An identification code precedes each set (lines, text or markers) along with the number of entries. Specific format and its size, etc. are discussed elsewhere [NAGE79] in detail.

In addition to the object retaining facility, the hardcopy interface can also be considered as a deviation from CORE specifications. However, this interface is highly modular and can be considered as an auxillary addition which is easily identifiable and removable. Finally, the interactive nature of the *ΦSCUBA* system does in a way reflect a slight deviation from the rigorous specifications of the Core System; however, this is a welcome enhancement provided by the base language APL.

V. EXPERIMENTAL RESULTS:

In this section, several displays created using the ΦSCUBA system are given. The world coordinate definitions of the displays created in Figures 4 to 6 are given in Appendix III.

Figure 4 shows a three point perspective view of a garage. Thr point perspective is obtained by having a view plane which intersects all the three principal axes in the world coordinate system. The view reference point is the right bottom corner and the center of projection is located at the roof level and is at a fair distance from the garage.

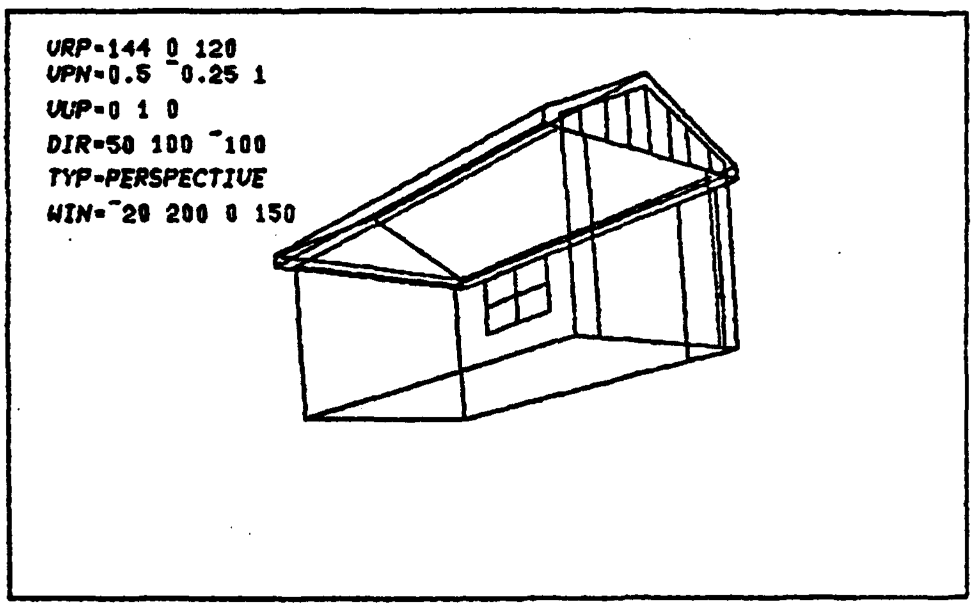

Figure 4: A Perspective View of a Garage

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PAGE

IS

MISSING

IN

ORIGINAL

DOCUMENT

14

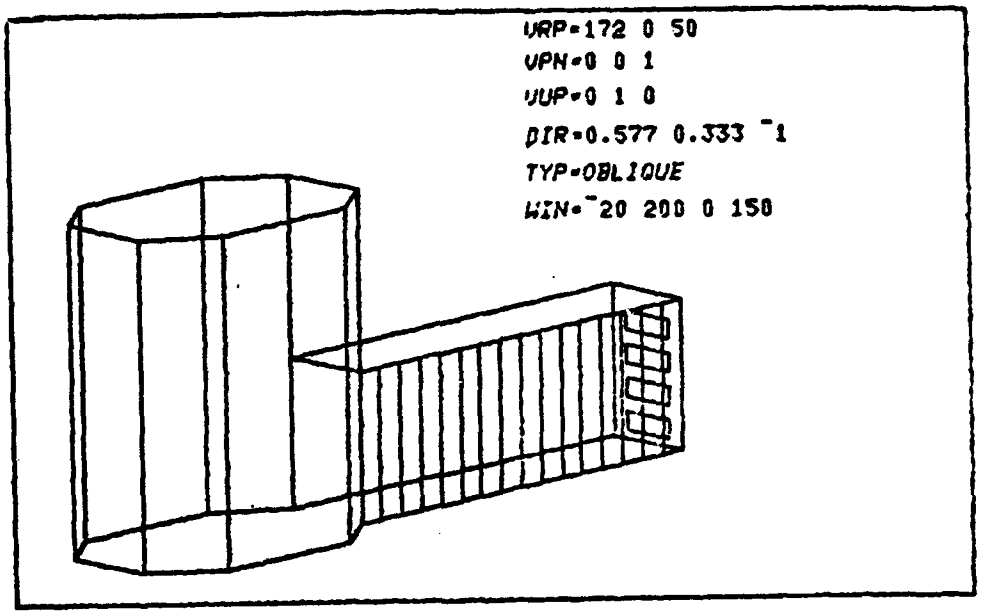

Figure 6: An Oblique View of a Building

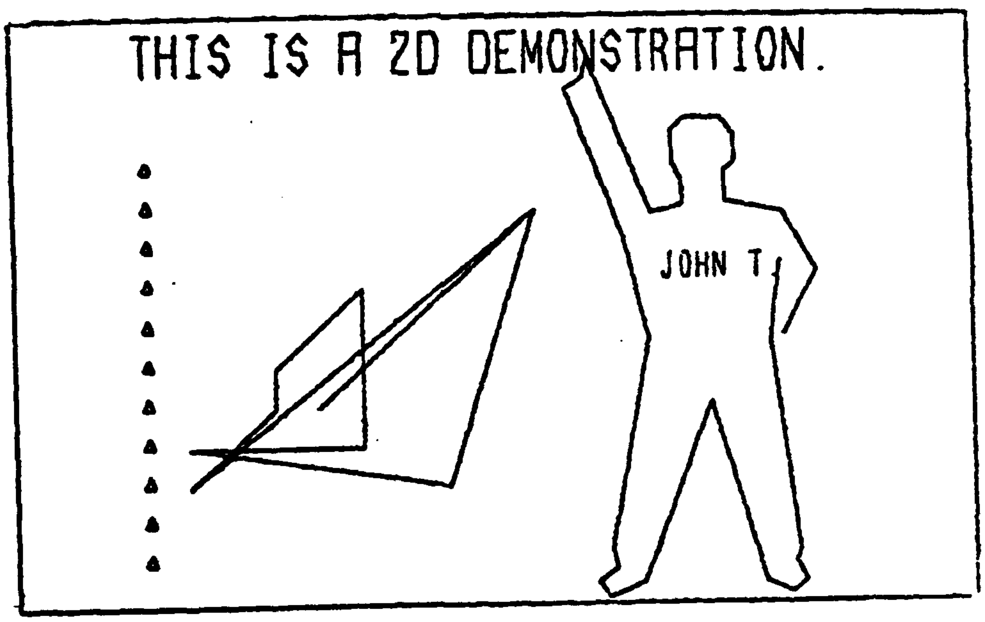

Figure 7: A 2D Demonstration

Figure 7 shows a two dimensional example. The size and spacing attributes for the two text strings are set by a call to SETPRAT function. The markers appearing on the left are plotted through MARKREL2 called in a loop. The outline of the man is constructed as a polyline through the invocation of a function POLYREL2. The set of lines shown in the figure is just an arbitrary set drawn through the POLYABS2 function. The position of the man is set through the MOVEABS2 function call.

An example of an application program using the ⌽*SCUBA* functions to plot curves is shown in Figure 8. The problem is to create a plot showing two simple trigonometric functions. An auxillary APL function STEP makes up intervals for the plots and the functions SIN and COS evaluate the respective trigonometric functions. The two curves are realized in two different ways. One is plotted as a series of two dimensional markers and the other is "pictured" as a two dimensional object. The function is written using the primitives and is enclosed in a segment for the purposes of adhering to CORE specifications. The results are given in Figure 9.

```
     ∇ PLOT2D;A;B;C;D;E;I
[1]    CREATE
[2]    A← 61 1 ρSTEP 0,(○2),○÷30
[3]    B←(SIN A)+(SIN 2×A)
[4]    C←(SIN A)+(COS 2×A)
[5]    D← 61 2 ρA,B
[6]    E← 61 2 ρA,C
[7]    I←1
[8]   LOOP:'*' MARKABS2 D[I;]
[9]    →(61≥I←I+1)/LOOP
[10]   MOVEABS2 E[1;]
[11]   POLYABS2(1 0)↓E
[12]   PICTURE
[13]   ⎕←HOME
[14]   CLOSE  ∇
```

```
     ∇ Z←STEP X
[1]    Z←X[1]+0,X[3]×
         ⍳⌈(X[2]-X[1])÷X[3]
     ∇

     ∇ X←SIN Y
[1]    X←1○Y
     ∇

     ∇ X←COS Y
[1]    X←2○Y
     ∇
```

Figure 8: Program for Plotting Trigonometric Curves

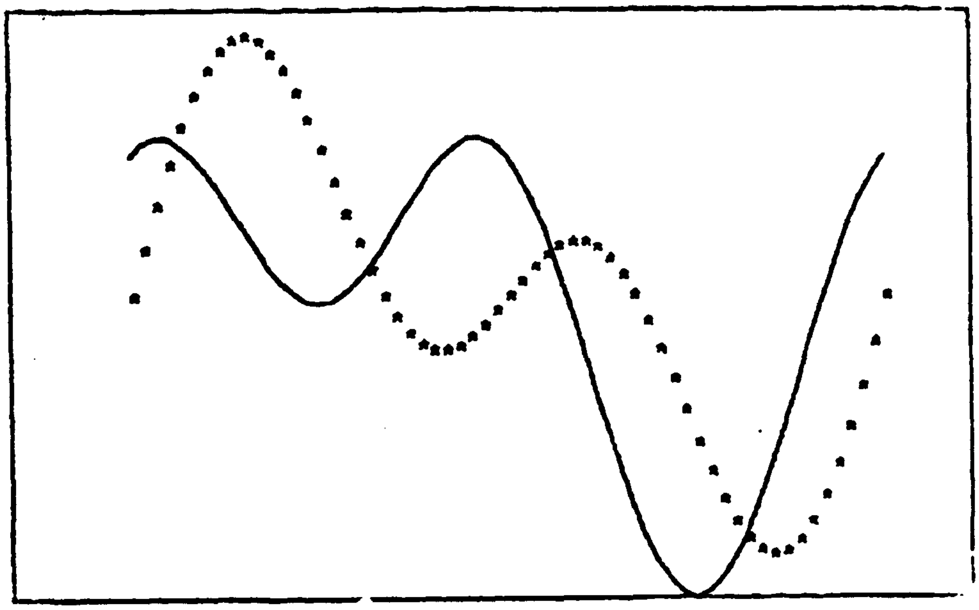

Figure 9: 2D Curve Plotting

Typical segment operations using the Garage example (which appeared in Figure 4) are illustrated in Figure 10.

```
CREATE
ENTER NAME OF THE SEGMENT [HIT RETURN IF UNNAMED]: SEGMENT1
.....
CLOSE
OPEN
ENTER NAME OF THE SEGMENT [HIT RETURN IF CURRENT]: (Return)
SETSGMT
.....
CLOSE
* IMAGE OF THE CURRENT SEGMENT RETAINED *
STORE
* WORLD DEFINITIONS OF THE SEGMENT SEGMENT1 HAS BEEN RETAINED *
LOAD
ENTER NAME OF THE SEGMENT: SEGMENT2
.....
DESTROY
ENTER NAME OF THE SEGMENT: SEGMENT3
* * * ERROR -- NAMED SEGMENT DOES NOT EXIST * * *
COPY
ENTER NAME OF THE SEGMENT:
.....
```

Figure 10: Illustration of a Few Segment Operations

VI. CONCLUSIONS:

A graphics system capable of meeting the specifications for a Level 2 (Buffered) Core System, in an APL operating environment, has been achieved. The application programmer being an APL user has the advantages of a simple and fast conversational system for the generation and maintenance of displays. Highly modular in nature, the implementation provides both two and three dimensional capabilities and supports full segmentation operations. Provisions are made to obtain various perspective, isometric and oblique views as well as side, front and top views commonly encountered in engineering applications. Knowledge of APL at an advanced level, while a distinct advantage on the part of the user, is not mandatory for creating and modifying pictures in the *ΦSCUBA* system. Experiments with the system so far indicate that the interactive handling of setting of attributes, etc. is both efficient and fast. One of the serious problems found so far has been that of workspace overflow in cases of complex objects or multiple segments. The system itself is still under development and as such has to be further tested and modified. Nevertheless one can feel the advantages of following GSPC methodology in designing a graphics system. Further, the task of a graphics application programmer is simplified when equipped with the functional capabilities of a Core System.

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APPENDIX I

TYPICAL USER SESSION:

A typical conversation with the ⌽*SCUBA* system is given in this appendix. The user input is given in the APL font.

```
        )LOAD NEWTHESIS
SAVED 17.20.15 05 22/79
THIS IS THE VERSION WITHOUT EXAMPLES AND WITHOUT HARDCOPY
        )ERASE CORE4
        )COPY THESIS GARAGE
SAVED 14.47.12 05/18/79
        COREINIT
        SETVIEW     ↔ Viewing parameters are set
VRP:
144 0 120
VPN:
0.5 ¯0.25 1
VPD:
0
TYP:
PERSPECTIVE
DIR:
50 100 ¯100
VUP:
0 1 0
WIN:
¯20 200 0 150
FBD:
¯50 400
NDC:
VPT 0.5 1.0 0.3 0.7/
        CREATE
ENTER NAME OF THE SEGMENT : [HIT RETURN IF UNNAMED] GARAGE
* SEGMENT DIRECTORY SAVED ON TSIO STORAGE *
        LISTSEG
```

SEGMENT NAME	VISIBILITY	STATUS	RESIDENCE
GARAGE	1	0	1

```
VISIBILITY - 1 FOR VISIBLE, 0 FOR INVISIBLE.
    STATUS - 1 FOR RETAINED, 0 FOR NONRETAINED.
 RESIDENCE - 1 FOR RESIDENT, 0 FOR NONRESIDENT.

    GARAGE ↔ Output primitives invoked through this function call
   PICTURE ↔ Fig. 4 will be displayed on the screen
     CLOSE
   SETSGMT
CST : TYPE R FOR RETAINING OR
      N OR RETURN OTHERWISE.    R
      OPEN ↔ Segment will be reopened for changes.
ENTER NAME OF THE SEGMENT:  [HIT RETURN IF CURRENT] (Return)
   SETPRAT ↔ New primitive attributes are set.
CIN:
HELP
```

THE FOLLOWING GIVES THE PRIMITIVE ATTRIBUTES THAT CAN BE SET IN ORDER TO VIEW THE SEGMENT WHICH IS CURRENTLY OPEN. IF NOT INITIALIZED, DEFAULT VALUES WILL BE USED FOR DISPLAYING.

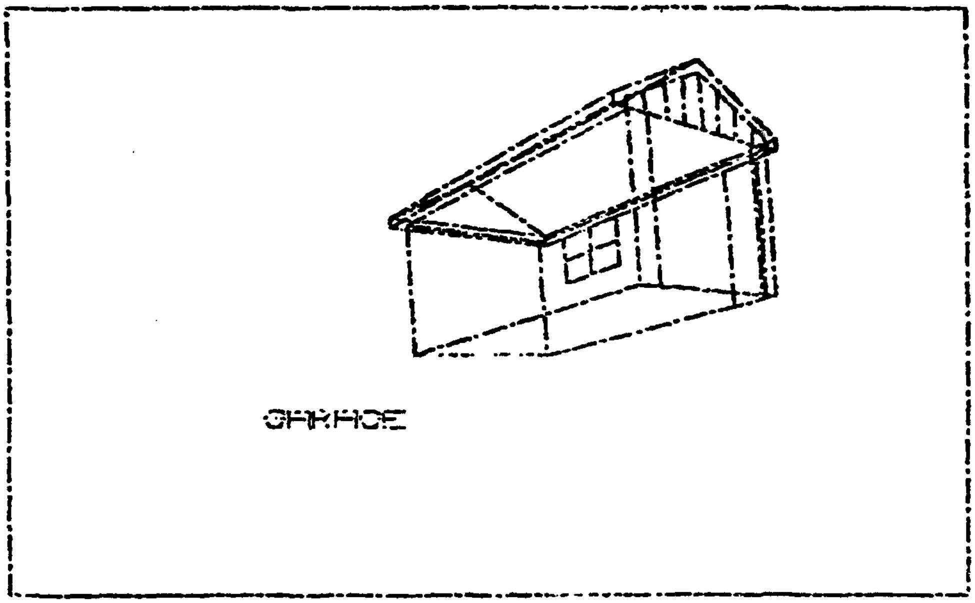
NAME	KEY	LENGTH	SPECIFICATION	DEFAULT
CURRENT INTENSITY	CIN	1	ABSOLUTE, 0 FOR DIMMED. 1 FOR BRIGHT.	1
CURRENT LINE STYLE	CLS	1	ABSOLUTE, 1 FOR FULL LINE. 2 FOR DOTTED LINE. 3 FOR DOT DASHED. 4 FOR SHORT DASHED. 5 FOR LONG DASHED.	1
CURRENT LINE WIDTH	CLW	1	ABSOLUTE, 1 FOR NORMAL. 2 FOR DOUBLE. 3 FOR TRIPLE. 4 FOR QUADRUPLE.	1
CURRENT CHAR. SIZE	CCS	2	ABSOLUTE, HEIGHT IN Y-UNITS BY WIDTH IN X-UNITS.	[0,0]
CURRENT CHAR. SPACE	CSP	2	ABSOLUTE, X-UNITS ALONG WIDTH AND Y-UNITS ALONG HEIGHT.	[0,0]

PROBABLY YOU CAN CHOOSE AND SET YOUR ATTRIBUTES NOW. HAPPY VIEWING!

CIN:
1
CLS:
3
CLW:
2
CCS:
10 8
CSP:
25 0
    INQUIRE
ENTER NAME OR ABBREVIATION : *SEG*
CURRENT SEGMENT : GARAGE
    INQUIRE
ENTER NAME OR ABBREVIATION : *TYPE*
CURRENT SEGMENT TYPE : RETAINED
    *MOVEABS*3 ¯20 ¯20 650
    TEXT 'GARAGE'
    PICTURE ↔ Generates a display with a different line style (see below)
    WRITE ↔ Text will be displayed.
    CLOSE

* IMAGE OF THE CURRENT SEGMENT HAS BEEN RETAINED *
    STORE
ENTER NAME OF THE SEGMENT : [HIT RETURN IF CURRENT] *GARAGE*
* WORLD DEFINITIONS OF THE SEGMENT GARAGE HAS BEEN RETAINED *
    DISPLAY
ENTER NAME OF THE SEGMENT : [HIT RETURN IF CURRENT] *GARAGE*
ENTER ONE OPTION : [ALL/PO/TO/MO/PT/PM/TM] *ALL*

* * * SEGMENT HAS NO MARKERS * * *



    RENAME
ENTER NAME OF THE SEGMENT : *GARAGE*
ENTER NEW NAME : *HOUSE*
* SEGMENT DIRECTORY SAVED ON TSIO STORAGE *
* SEGMENT GARAGE HAS BEEN RENAMED AS HOUSE. *
    OPEN
ENTER NAME OF THE SEGMENT : [HIT RETURN IF CURRENT] *HOUSE*
* * * NAMED SEGMENT NOT IN WORK SPACE * * *
* * * LOAD THE SEGMENT BEFORE OPENING AGAIN * * *
    LOAD
ENTER NAME OF THE SEGMENT : *HOUSE*
* YOUR SEGMENT HAS BEEN LOADED *
    OPEN

    .
    .
    .
    etc.

APPENDIX II

LIST OF ΦSCUBA FUNCTIONS:

A complete list of ΦSCUBA functions is included in this section. The functions contained and explained in the GSPC77 report are identified with a '+'. Additional functions which may be of direct use to the ΦSCUBA user are identified with '*'; explanation of these follows the list. The remaining functions are mostly used internally.

)GRP CORE1

ADJUST	CLIPLINE	CLIP3D	COS	CWRITE
CODE	DECODE	DISPLINE	DISPOINT	DRAWABS2+
DRAWABS3+	DRAWREL2+	DRAWREL3+	HOME	INVERT
LINE	MARKABS2+	MARKABS3+	MARKREL2+	MARKREL3+
MARKPLOT*	MOVEABS2+	MOVEABS3+	MOVEREL2+	MOVEREL3+
NAMETRANS	NMATRIX	NWRITE	OBLIQUE	ORTHO
PARAPED	PICTURE*	POLYABS2+	POLYABS3+	POLYREL2+
POLYREL3+	PROJECT	PYRAMID	RESCALEX	RESCALEY
RESETSC1	RESETSC2	SCALE	SCALEX	SCALEY
SELECT	SETSC	SIN	SWAP	TEXT+
TRANSFORM	VWRITE	WINDOW	WRITE*	

* MARKPLOT - Creates and displays the image of the markers described by the marker primitives.

* PICTURE - Creates and displays the image of the wire frame drawing described by the line primitives.

* WRITE - Creates and displays the image of the text described by the text primitive.

)GRP CORE2

CREATE+	COPY*	CLOSE+	DESTROY+	DESTROYALL+
DISPLAY*	ERASE*	INITDIRY*	LISTSEG*	LOAD*
LOADDIRY*	NAME*	OPEN*	PADΔ	RENAME+
SRCHDIR	STORDIRY*	STORE*		

* COPY - Copies the contents of a retained segment's image file into work space.

* DISPLAY - Displays the image (whole or part) of a segment anytime its image definition is in workspace.

* ERASE - Deletes the retained object definition file of a segment from the system.

* LISTSEG - Displays the segment directory to the user.

* LOAD - Loads the retained object definition file of a segment onto the workspace.

*LOADDIRY - Loads the retained segment directory to the workspace.

* *NAME* - Names an unnamed segment for the purposes of retaining, if needed.

* *OPEN* - Opens a closed segment for picture additions or other output primitive invocations.

* *STORDIRY* - Retains the current segment directory as a TSIO file.

* *STORE* - Retains the current object definitions in a segment as a TSIO file.

* *INITDIRY* - Initializes the segment directory.

)*GRP CORE*3

CHK2D	*CHK3D*	*CHKCLOSE*	*CHKOPEN*	*CHKVTV*
COREINIT+	*IGLTB*	*INQUIRE**	*PEEL*	*QQP*
*SETCTRL**	*SETLEFT*+	*SETREST*	*SETRIGHT*+	*SETSGMT**
*SETVIEW**	*SETPRAT**	*SETVISB*+	*TYPDET*	

* *INQUIRE* - All the possible inquiries such as values of primitive attributes, viewing parameters, segment attributes, etc. are made through this function.

* *SETCTRL* - Sets the clipping options.

* *SETSGMT* - Sets the segment type.

* *SETVIEW* - Sets the viewing parameters.

* *SETPRAT* - Sets the values of primitive attributes.

)*GRP CORE*4

*ROTGEN*3*D**	*ROTATE*3*D**	*REFLECT*3*D**	*SCALE*3*D**	*SHEAR*3*D**
*TRANS*3*D**				

* *ROTGEN*3*D* - Rotates the object about an arbitrary axis.

* *ROTATE*3*D* - Rotates the object about a coordinate axis.

* *REFLECT*3*D*- Generates a reflection of the object about any principal plane.

* *SCALE*3*D* - Scales the object in any or all directions.

* *SHEAR*3*D* - Produces a shearing of the object in required directions.

* *TRANS*3*D* - Translates the object to a required point in world coordinate space.

)*GRP COREV*

BOUNDS	*CMNT*	*CTRLLIST*	*CURPOS*	*CURSEG*
DEFGLBS	*FLAG2D*	*FLAG3D*	*INCHAR*	*LRFLAG*
OPENFLG	*PRATLIST*	*PREGLBS*	*ROWKEY*	*SC*
SCRNDIST	*SGMTDIRY*	*SYM*	*SYSGLBS*	*SCSET*
VIEWLIST	*WC*	*GWCDEF*	*GMKDEF*	*GTXDEF*
GLIMGE	*GMIMGE*	*OLDSC*		

)GRP HARDCOPY

DROPOS	HCOPYINIT*	JOBSECU	NUMTOCHR	PLOTFILE
PRINT	PURGE	RJERJO	TRANSFER*	FILE
ACT	FOR	JB	JOBSECU	LL
N	PF	PN	PRT	STRT
CT				

* HCOPYINIT - Initializes the TSIO file to record 'pen movements'.

* TRANSFER - Transfers the screen display to the required hardcopy unit.

)GRP TSIO

CHK	DELETE	RELEASE	TRY	OLE
PID	Q			

)GRP TEKGRP

CONVERT	CORD	ERASE	L	LT
P	SCREEN	SIZE	WRITE	CH
H	R	S	XYDIMN	ALPH
BS	CSC	CSV	CUR	GRF
HXY	OM	RS	US	W
XL	YL			

APPENDIX III

The world coordinate definitions of the examples used in constructing Figures 4, 5 and 6 are given below. A left handed system is assumed.

GARAGE (80 × 4 array)

0	0	0	0
0	¯12	84	120
1	¯12	90	120
1	72	120	120
1	156	90	120
1	156	84	120
1	144	84	120
1	144	90	120
1	72	114	120
1	0	90	120
1	0	0	120
1	144	0	120
1	144	84	120
1	¯12	84	120
0	18	84	120
1	18	0	120
0	126	84	120
1	126	0	120
0	156	84	396
1	156	90	396
1	72	120	396
1	¯12	90	396
1	¯12	84	396
0	¯12	90	396
1	156	90	396
0	156	84	396
1	¯12	84	396

0	144	84	390
1	0	84	390
0	144	0	390
1	0	0	390
0	144	84	390
1	144	0	390
0	0	84	390
1	0	0	390
0	72	120	120
1	72	120	396
0	156	90	120
1	156	90	396
0	156	84	120
1	156	84	396
0	144	0	120
1	144	0	390
0	144	84	390
1	144	84	120
0	144	0	129
1	144	80	129
1	144	80	159
1	144	0	159
0	144	48	282
1	144	48	354
1	144	80	354
1	144	80	282
1	144	48	282

0	144	48	318
1	144	80	318
0	144	64	354
1	144	64	282
0	¯12	90	396
1	¯12	90	120
0	¯12	84	396
1	¯12	84	120
0	0	84	390
1	0	84	120
0	0	0	390
1	0	0	120
0	15	95	120
1	15	84	120
0	36	102	120
1	36	84	120
0	54	108	120
1	54	84	120
0	72	114	120
1	72	84	120
0	90	108	120
1	90	84	120
0	108	102	120
1	108	84	120
0	129	95	120
1	129	84	120

STAIRS (42 × 4 array)

0	0	0	0
0	0	0	10
1	0	60	10
1	13	60	10
1	13	45	10
1	26	45	10
1	26	30	10
1	39	30	10
1	39	15	10
1	52	15	10
1	52	0	10
1	0	0	10
0	0	0	30
1	0	60	30

1	13	60	30
1	13	45	30
1	26	45	30
1	26	30	30
1	39	30	30
1	39	15	30
1	52	15	30
1	52	0	30
1	0	0	30
1	0	0	10
0	0	60	10
1	0	60	30
0	13	60	30
1	13	60	10

0	13	45	10
1	13	45	30
0	26	45	30
1	26	45	10
0	26	30	10
1	26	30	30
0	39	30	30
1	39	30	10
0	39	15	10
1	39	15	30
0	52	15	30
1	52	15	10
0	52	0	10
1	52	0	30

BUILDING (101 × 4 array)

0	0	0	0
0	50	0	50
1	80	0	50
1	92	0	66
1	172	0	66
1	172	0	96
1	92	0	96
1	80	0	112
1	50	0	112
1	38	0	96
1	38	0	66
1	50	0	50
0	50	110	50
1	80	110	50
1	92	110	66
1	92	110	96
1	80	110	112
1	50	110	112
1	38	110	96
1	38	110	66
1	50	110	50
0	92	110	66
1	92	50	66
1	172	50	66
1	172	50	96
1	92	50	96
1	92	110	96
0	172	50	66
1	172	0	66
0	172	0	96
1	172	50	96
0	50	0	50
1	50	110	50
0	38	110	66
1	38	0	66
0	38	0	96
1	38	110	96
0	50	110	112
1	50	0	112
0	80	0	112
1	80	110	112
0	92	110	96
1	92	0	96
0	92	0	66
1	92	110	66
0	80	110	50
1	80	0	50
0	92	50	66
1	92	50	96
0	97	0	66
1	97	50	66
0	102	0	66
1	102	50	66
0	107	0	66
1	107	50	66
0	112	0	66
1	112	50	66
0	117	0	66
1	117	50	66
0	122	0	66
1	122	50	66
0	127	0	66
1	127	50	66
0	132	0	66
1	132	50	66
0	137	0	66
1	137	50	66
0	142	0	66
1	142	50	66
0	147	0	66
1	147	50	66
0	152	0	66
1	152	50	66
0	157	0	66
1	157	50	66
0	162	0	66
1	162	50	66
0	167	0	66
1	167	50	66
0	172	0	66
0	172	3	72
1	172	9	72
1	172	9	90
1	172	3	90
1	172	3	72
0	172	14	72
1	172	20	72
1	172	20	90
1	172	14	90
1	172	14	72
0	172	25	72
1	172	31	72
1	172	31	90
1	172	25	90
1	172	25	72
0	172	36	72
1	172	42	72
1	172	42	90
1	172	36	90
1	172	36	72
0	172	47	72

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SCHOOL OF COMPUTER SCIENCE

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TR74-002	Oct. 1974	W. D. Wasson R. McIssaac	A New Spanning Tree Algorithm
TR74-003	Oct. 1974	U. G. Gujar	Remote Job Entry and Output Through APL
TR75-004	Apr. 1975	U. G. Gujar	Subroutines with Variable Number of Arguments
TR75-005	July 1975	L. E. Garey	Block Methods for Nonlinear Volterra Integral Equations
TR75-006	Aug. 1975	D. M. Fellows	Comments on "A General Fortran Emulator for IBM 360/370 Random Number Generator 'RANDU'"
TR75-007	Aug. 1975	L. E. Garey M. LeBlanc	Quadrature Formulae for Functions of Two Variables and Applications
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TR75-009	Oct. 1975	D. M. Miller	An Algorithm for Determining The Chromatic Number of a Graph
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TR76-012	Mar. 1976	Patrick P. Emin	A Partition Monitor for Fast-Batch-Processing with Limited Execution (Fable)
TR76-013	Dec. 1976	Uday G. Gujar J. A. Fitzgerald	A Driver for Raster-Like Plotting Devices
TR77-014	Jan. 1977	Uday G. Gujar David M. Fellows	Automatic Job Scheduling in HASP
TR79-015	May 1979	Uday G. Gujar John M. DeDourek Marion E. McIntyre	A Method for Designing a Lexical Analyzer
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